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AN INTRODUCTION TO STATISTICAL TECHNIQUES FOR FOUNDRY EXPERIMENTS

by

C. A. Rowe*

INTRODUCTION

In all experimental work the observations made are always subject to experimental error. Only recently has it begun to be generally realized that in order to judge the trustworthiness of the data which are collected, they must be compared with an estimate of their error, an operation known to the statistician as a "test of significance." The lack of this test of significance is one of the main reasons for the unsatisfactory nature of much foundry experimentation.

The object of this paper is to introduce the reader to some of the statistical techniques which can be used as a guide to sound decisions in the foundry. A knowledge of advanced mathematics will not be necessary. Simple arithmetic and the substitution of numbers into formulas is all the mathematics that will be required. The basic mathematical concepts underlying the statistical techniques described are somewhat involved and are beyond the scope of this paper.

INITIAL ASPECTS

There is a definite need for a more reliable method of making technical and operational decisions in the foundry. Generally, operating decisions are made by qualitatively observing alternative methods of doing the task. At best, a few trials may be run with each of the alternative methods, the data collected, and a decision made on the basis of these data.

Suppose, for example, that the plant metallurgist was trying to decide whether heat treatment X would yield higher Charpy impact strengths than the standard heat treatment normally in use. The investigator might decide to check ten specimens of steel from the same heat, heat treating five in the standard way and five using heat treatment X. On taking the average Charpy impact strengths, he then might find the standard heat treatment to yield an average value of 43 foot-pounds and heat treatment X to yield an average value of 48 foot-pounds. The question is: is he justified in concluding that heat treatment X produces higher Charpy impact results than the standard heat treatment? It is in a situation such as this that simple statistical techniques can be used as a guide to making the proper decision—a decision which might save a considerable sum of money over a period of time.

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The apparent difference between the standard heat treatment and heat treatment X in the above example may actually exist, but on the other hand, the difference may be due merely to chance. Perhaps if several hundred specimens were taken instead of 10, there would have been no difference in the averages of the two methods. Obviously, the experimenter cannot take an infinite number of specimens, and the in-plant experimenter in the jobbing foundry may be limited indeed in the number of tests he can make. The use of statistical techniques is to give the experimenter a knowledge of the variation which can occur due to chance. Armed with this knowledge, he will then be able to discern between different samples (i.e., groups of specimens) and determine if these samples truly represent different quantities.

The basis of many statistical techniques is the consideration that the apparent difference between various samples is due only to pure chance. This assumption, that no significant difference exists between the two or more different processes or samples, is known to the statistician as a *Null Hypothesis.* When an experimenter uses statistical techniques to determine whether a new process he had tried was better than the existing process, he first adopts the Null Hypothesis that there is no difference between the new process and the standard process. He must then calculate the probability that the apparent difference between the "old" process and the "new" process occurred by chance alone. If this probability is small (say one chance in 20 or 100) then the Null Hypothesis can be rejected and it can be concluded that a true difference exists between processes.

When a result is obtained which is very unlikely to have arisen by chance, the result is said to be *statistically significant.* This simply means that it would be unrealistic to ascribe it to chance, and the difference must, in all common sense, be accepted as a real difference. Since the judgment is based on probability, falling short of absolute certainty, the degree of confidence in the reality of the difference must be indicated. The degree of confidence is generally described as "Probably Significant," "Significant," or "Highly Significant." Thus, a result that would only arise in one trial in twenty on the basis of pure chance should be described as "Probably Significant." A result that would arise on the basis of pure chance only once in a hundred trials should be described as "Significant." A result that would arise by chance only once in a thousand trials should be described as "Highly Significant." A better way to do this is not simply to use words

of this kind, but to quote the level of probability as the 5 percent level, the 1 percent level, and the 0.1 percent level, respectively.

In the following sections of this paper, the reader will be introduced to the "t" test, the "F" test, and experimental design for the Analysis of Variance. The t test is used to determine the difference between two samples or processes; the F test is used to determine the difference between three or more samples; and the section on experimental design for the Analysis of Variance will illustrate the design of factorial experiments in order to best apply a statistical test of significance. The reader must be aware throughout that it is impossible in a paper of this nature to deal with the basic underlying mathematics and derivations of the formulas which are presented. This information is available, of course, in the reference books listed at the end of this paper. The sections dealing with the t test and F test, however, are presented in such a manner that the careful reader may be able to apply them to his use merely by using his own data in the formulas and working out the result by analogy.

THE "t" TEST

The use of the t test can best be illustrated by working out a simple example. Suppose that a melter wanted to determine whether the use of calcium in the deoxidation process would improve the ductility of his steel. He deoxidized one half of the heat in one ladle with aluminum only and deoxidized the other half of the heat in another ladle using calcium-manganese-silicon alloy along with the usual addition of aluminum. He then poured five keel blocks from each ladle, each of which would be used for a tensile specimen. Using care to heat treat and handle all bars in the same manner, he obtained the data for the elongation of the tensile specimens:

Al only	Al plus Calcium
28%	34%
29%	27%
25%	30%
23%	26%
30%	33%
Average = 27.0%	Average = 30.0%

The data show that average elongation obtained by using only aluminum is 27.0 percent, while the average elongation obtained by using calcium along with aluminum is 30.0 percent. The question is: can he conclude from these data that the use of calcium is truly beneficial, and thus justify the extra cost of its use? This is where the t test can be used to guide his decision. Let us now perform the t test.

The formula for t is:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sigma} \sqrt{\frac{n_1 \times n_2}{n_1 + n_2}}$$

where: $\overline{X}_1$ = average value of elongation for steel deoxidized with Al only

$\overline{X}_2$ = average value of elongation for steel deoxidized with Al plus Ca

n_1 = number of specimens in the sample of steel deoxidized with Al only

n_2 = number of specimens in the sample of steel deoxidized with Al plus Ca

σ = best estimate of the standard deviation; to be referred to here merely as the standard deviation

It can be seen that all the values of the terms on the right-hand side of this equation are known except the value of σ. $\overline{X}_1$ equals 27.0 percent; $\overline{X}_2$ equals 30.0 percent; n_1 equals 5; and n_2 equals 5. The problem then is to determine the value of σ. This is obtained from the formula:

$$\sigma^2 = \left[\Sigma(x_1^2) - \frac{(\Sigma x_1)^2}{n_1} + \Sigma(x_2^2) - \frac{(\Sigma x_2)^2}{n_2}\right] \Big/ (n_1 + n_2 - 2)$$

where: σ^2 = the variance; merely the square of the standard deviation

Σx_1 = the summation of all the "Al only" terms

Σx_2 = the summation of all the "Al plus Ca" terms

$\Sigma(x_1^2)$ = the summation of the squares of the "Al only" terms

$\Sigma(x_2^2)$ = the summation of the squares of the "Al plus Ca" terms

$(n_1 + n_2 - 2)$ = the number of degrees of freedom; 2 less than the total number of specimens (i.e. $n_1 - 1 + n_2 - 1$).

So that the reader may more easily follow the calculations, let us set up the original data as follows:

Al only	x_1^2	Al + Ca	x_2^2
28	784	34	1156
29	841	27	729
25	625	30	900
23	529	26	676
30	900	33	1089
$135 = \Sigma x_1$	$3679 = \Sigma(x_1^2)$	$150 = \Sigma x_2$	$4550 = \Sigma(x_2^2)$
$\overline{X}_1 = 27.0$		$\overline{X}_2 = 30.0$	

Substituting into the formula for σ^2:

$$\sigma^2 = \left[3679 - \frac{(135)^2}{5} + 4550 - \frac{(150)^2}{5}\right] \Big/ (5 + 5 - 2)$$

$$= [3679 - 3645 + 4550 - 4500]/(8)$$

$$\sigma^2 = 10.5$$

Taking the square root of σ^2 gives the value for σ:

$$\sigma = \sqrt{10.5} = 3.24$$

Knowing the value for σ we can now go back to the initial formula for t and substitute in all the values on the right-hand side:

$$t = \frac{27.0 - 30.0}{3.24} \sqrt{\frac{5 \times 5}{5 + 5}}$$

$$= \frac{3.0}{3.24} \sqrt{2.5}$$

$$t = 1.46$$

Having the value of t, all that remains is to refer to the table of t shown in Table I to see if the value of t is large enough that the data can be considered significant. Table I gives the degrees of freedom and the t values. It was shown above that the degrees of freedom for this example were $(5-1)+(5-1)=8$.

TABLE I—Table of t

Degrees of Freedom	t 5%	1%	0.1%
1	12.71	63.66	636.62
2	4.30	9.93	31.60
3	3.18	5.84	12.94
4	2.78	4.60	8.61
5	2.57	4.03	6.86
6	2.45	3.71	5.96
7	2.37	3.50	5.41
8	2.31	3.36	5.04
9	2.26	3.25	4.78
10	2.23	3.17	4.59
11	2.20	3.11	4.44
12	2.18	3.06	4.32
13	2.16	3.01	4.22
14	2.15	2.98	4.14
15	2.13	2.95	4.07
16	2.12	2.92	4.02
17	2.11	2.90	3.97
18	2.10	2.88	3.92
19	2.09	2.86	3.88
20	2.09	2.85	3.85
21	2.08	2.83	3.82
22	2.07	2.82	3.79
23	2.07	2.81	3.77
24	2.06	2.80	3.75
25	2.06	2.79	3.73
26	2.06	2.78	3.71
27	2.05	2.77	3.69
28	2.05	2.76	3.67
29	2.04	2.76	3.66
30	2.04	2.75	3.65
40	2.02	2.70	3.55
60	2.00	2.66	3.46
120	1.98	2.62	3.37
∞	1.96	2.58	3.29

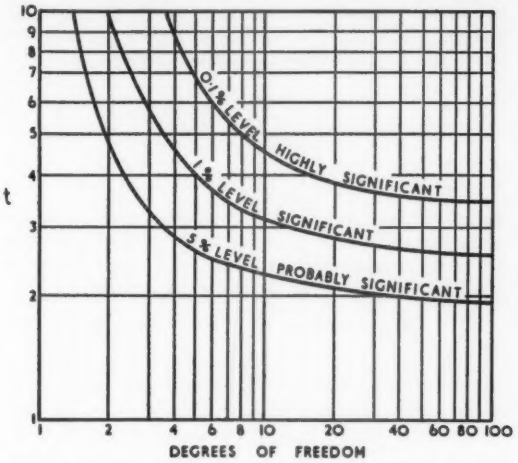

Figure 1—Graphs of t for the 5%, 1% and 0.1% significance level. If the calculated value for t is greater than the value shown above for the appropriate number of degrees of freedom, the indicated level of significance is reached. (Moroney)[1]

It is seen from Table I that for 8 degrees of freedom a value of t of at least 2.31 is required if the data are to be significant at the 5 percent level; significance at the 1 percent level would require a value of t of at least 3.36; and significance at the very high level of 0.1 percent would require a value of t of at least 5.04. The information in Table I is also shown in graphical form in Figure 1.

The value of $t = 1.46$ obtained in the above example is well below even the 5 percent significance level. Therefore, the apparent difference between the elongation of the steel deoxidized with aluminum only and the steel deoxidized with aluminum plus calcium has not been proven at a statistically significant level. On the basis of these data, it would be foolish for the melter to spend the extra money for calcium in his deoxidation process.

The reader must be certain that he properly understands the meaning of the above result. The result "not significant" from a statistical significance test is not so much a complete acquittal as a verdict of "not proven." There may actually be a real improvement in the elongation due to the use of calcium, but the evidence so far is insufficient to warrant the extra expense. Perhaps if more tests were run it would be possible to show a statistically significant improvement due to the use of calcium.

Another brief example will be used to further illustrate the practical use of the t test. Suppose a very difficult scabbing and/or penetration problem was encountered in a problem casting. Two types of proprietary washes are commonly in use in the foundry and it is desired to see which wash might be best in this particular application. Several molds are washed with the first wash, Wash A, and several molds washed with the other, Wash B. After the

molds are poured, the castings are shaken out, shot blasted and rated for scabbing and/or penetration according to the following rating system:

0 — Excellent
1 — Slight defects
2 — Poor
3 — Very bad

Eight castings using Wash A and seven castings using Wash B were poured (it is not necessary that an equal number of specimens be in each group to apply the t test). The results were as follows:

Wash A	Wash B
1	2
0	3
2	3
1	1
3	2
0	3
1	2
1	

Applying all the procedures shown in the previous example, the calculations used to obtain the value of t are as follows:

Wash A	x_1^2	Wash B	x_2^2
1	1	2	4
0	0	3	9
2	4	3	9
1	1	1	1
3	9	2	4
0	0	3	9
1	1	2	4
1	1	—	—
—	—	$16=\Sigma x_2$	$40=\Sigma(x_2^2)$
$9=\Sigma x_1$	$17=\Sigma(x_1^2)$	$\overline{X}_2=\frac{16}{7}=2.28$	

$$\overline{X}_1=\frac{9}{8}=1.12$$

$$\sigma^2=\left[\Sigma(x_1^2)-\frac{(\Sigma x_1)^2}{n_1}+\Sigma(x_2^2)-\frac{(\Sigma x_2)^2}{n_2}\right]\Big/(n_1+n_2-2)$$

$$=\left[17-\frac{(9)^2}{8}+40-\frac{(16)^2}{7}\right]\Big/(8+7-2)$$

$$=10.3/13$$

$$\sigma^2=0.79$$

Therefore $\sigma=\sqrt{0.79}=0.89$

$$t=\frac{\overline{X}_1-\overline{X}_2}{\sigma}\sqrt{\frac{n_1\times n_2}{n_1+n_2}}$$

$$=\frac{1.12-2.28}{0.89}\sqrt{\frac{8\times 7}{8+7}}$$

$$=\frac{1.16}{0.89}\sqrt{3.73}$$

$t=2.52$, with 13 degrees of freedom

Referring to Table I it is seen that at 13 degrees of freedom (i.e., $8-1+7-1$ samples) a value of t of at least 2.16 is required for significance at the 5 percent level. A value of 3.01 at the 1 percent level is required, and a value of 4.22 at the 0.1 percent level is required. Hence, the value of $t=2.52$ is significant at the 5 percent level. This means that the difference in the results obtained with the two washes could not have occurred due to chance more than once in twenty trials. On this basis it is justifiable to conclude that Wash B is better than Wash A with regard to the elimination of scabbing and/or penetration in this problem casting.

The above examples have shown two typical situations which might conceivably arise in the everyday operation of a foundry, and how the t test can be used as a guide in decision-making. Any foundryman should be able to think of several similar applications in his own shop for a statistical test of this nature.

THE "F" TEST

There is no reason why only two groups of data should be compared at once. In order to test the significance of three or more groups of data, a test of statistical significance known as the "F" test is available. This test, also known as the Variance Ratio Test, will now be discussed.

Suppose that a foundryman were interested in learning whether the amount of welding time on a particular casting could be reduced by making it in a dry sand or a CO_2 sand mold instead of a green sand mold. The man realizes that it will be more expensive to make this casting in a dry or CO_2 sand mold but feels that the extra molding expense can be justified if the welding costs can be significantly reduced. He then makes several castings in each of the molding mediums, taking care that all other variables are as nearly constant as possible. The welding time on each casting is carefully noted so that a comparison can be made. Fourteen castings were made and the welding times in minutes for these castings are as follows:

	Green Sand	Dry Sand	CO_2 Sand
	19	21	14
	28	15	20
	14	11	15
	29	12	19
	15	21	—
	—	—	
Total	105	80	68
Average	21	16	17

The question now is whether or not these data show a significant difference in welding time to exist between castings made in the various molding

mediums. At first glance it may appear that an obvious difference exists since the average value of welding time for castings made in green sand molds is approximately 30 percent greater than for dry sand molds. It will be shown, however, that a decision based on this apparent difference could turn out to be an expensive mistake for this foundryman. The use of the F test to determine the significance of these data will now be illustrated. This can best be done by showing all calculations and then discussing each step:

Green Sand	x_1^2	Dry Sand	x_2^2	CO_2 Sand	x_3^2
19	361	21	441	14	196
28	784	15	225	20	400
14	196	11	121	15	225
29	841	12	144	19	361
15	225	21	441	——	——
105=	2407=	80=	1372=	68=	1182=
Σx_1	Σx_1^2	Σx_2	Σx_2^2	Σx_3	Σx_3^2

$\overline{X}_1 = \frac{105}{5} = 21 \qquad \overline{X}_2 = \frac{80}{5} = 16 \qquad \overline{X}_3 = \frac{68}{4} = 17$

Preliminary Calculations:

$\Sigma x = \Sigma x_1 + \Sigma x_2 + \Sigma x_3$

$= 105 + 80 + 68$

$\Sigma x = 253$

$\Sigma x^2 = \Sigma x_1^2 + \Sigma x_2^2 + \Sigma x_3^2$

$= 2407 + 1372 + 1182$

$\Sigma x^2 = 4961$

$N = N_1 + N_2 + N_3 = 5 + 5 + 4 = 14$

Correction Factor =

$$CF = \frac{(\Sigma x)^2}{N} = \frac{(253)^2}{14} = 4572$$

Total Sum of Squares =

$\Sigma x^2 - CF = 4961 - 4572 = 389$

There are $N = 14$ items and therefore $N - 1 = 13$ degrees of freedom.

Between Sample Sum of Squares =

$$\frac{(\Sigma x_1)^2}{N_1} + \frac{(\Sigma x_2)^2}{N_2} + \frac{(\Sigma x_3)^2}{N_3} - CF =$$

$$\frac{(105)^2}{5} + \frac{(80)^2}{5} + \frac{(68)^2}{4} - 4572 =$$

$2205 + 1280 + 1156 - 4572 = 69$

There are 3 samples and therefore $3 - 1 = 2$ degrees of freedom.

Within Sample Sum of Squares =

Total Sum of Squares minus Between Sample Sum of Squares $= 389 - 69 = 320$

There are 13 minus 2, or 11 degrees of freedom.

Variations Between Samples =

$$\frac{69}{2} = 34.5 \qquad (2 \text{ d.f.})$$

Variance Within Samples =

$$\frac{320}{11} = 29.1 \qquad (11 \text{ d.f.})$$

$$F = \frac{\text{Greater Variance Estimate}}{\text{Lesser Variance Estimate}}$$

$$= \frac{34.5}{29.1}$$

$$F = 1.19 \frac{(2)}{(11)}$$

Reference to Tables of Variance Ratio shows that the data are not statistically significant.

The data are again listed along with the square of each item. The square of each item is shown under the columns marked x_1^2, x_2^2 and x_3^2. The symbol Σx_1 simply refers to the sum of all the terms of the Green Sand column. The symbol Σx_1^2 refers to the sum of all the terms in the x_1^2 column. The symbol $\overline{X}_1$ is the average of the items in the Green Sand column. The symbols Σx_2, Σx_2^2, $\overline{X}_2$ and Σx_3, Σx_3^2, $\overline{X}_3$ refer to the dry sand and CO_2 sand data, respectively.

The *Preliminary Calculations* show the calculation of the terms Σx, Σx^2 and N. The term Σx is the sum of all the items in columns Green Sand, Dry Sand and CO_2 Sand. The term Σx^2 is the sum of all the squared terms. The term N is the number of castings which were made.

Referring to the preliminary calculations, a very important quantity known as the *Correction Factor* is next to be calculated. This value is found to be 4572. The correction factor will enter into the computation of all further sums of squares which are directly computed.

The *Total Sum of Squares* is next computed. This is the value of the Σx^2 term, calculated under the preliminary calculations, minus the correction factor. This value is calculated to be 389. It is very important to know the number of degrees of freedom which are associated with this value. The number of degrees of freedom is always one less than the total number of items on which the sum of squares is based. Since there are 14 items which make up the total sum of squares, there must be 13 degrees of freedom.

In order to get the *Between Sample Sum of Squares,* we find the sum of the squares of each sample total divided by the number of items in the sample. The correction factor is subtracted from the total of these three terms. The value of the Between Sample Sum of Squares is seen to be 69. The number of degrees of freedom is one less than the number of samples. Since there are 3 samples, there are therefore 2 degrees of freedom on which this value for the Between Sample Sum of Squares is based.

The *Within Sample Sum of Squares* is then found by subtracting the Between Sample Sum of Squares from the Total Sum of Squares, and is seen to be 320. It is not necessary to subtract the correction factor from this term since it has not been calculated directly. The number of degrees of freedom is found simply by subtracting the number of degrees of freedom in the Between Sample Sum of Squares (2) from the number of degrees of freedom in the Total Sum of Squares (13). Therefore, there are 11 degrees of freedom associated with the Within Sample Sum of Squares.

We are now in a position to calculate the variances between samples and within samples and to determine the value of the variance ratio, F. The *Variance Between Samples* is equal to the Between Sample Sum of Squares divided by its degrees of freedom. This is found to be 69 divided by 2 which equals 34.5. The *Variance Within Samples* is equal to the Within Sample Sum of Squares divided by its degrees of freedom. This is found to be 320 divided by 11 which equals 29.1. The value of F is equal to the greater variance estimate divided by the lesser variance estimate. The greater variance estimate in this example is seen to be 34.5 and the lesser variance estimate is seen to be 29.1. Hence, F equals 34.5 divided by 29.1 and is found to be 1.19, with 2 degrees of freedom in the numerator and 11 degrees of freedom in the denominator.

All that remains now is to refer to the Tables of Variance Ratio shown in Tables II, III and IV to determine if the value of F is large enough to be considered statistically significant. Referring to Table II, with 2 degrees of freedom in the greater variance estimate and 11 degrees of freedom in the lesser variance estimate, it is seen that a value of F of at least 4.0 is required if the data are to be considered statistically significant at the 5 percent level. Tables

TABLE II—Table of Variance Ratio

5% Significance Level

Number of Degrees of Freedom in the Lesser Variance Estimate (or Denominator Term)	Number of Degrees of Freedom in the Greater Variance Estimate (or Numerator Term)								
	1	2	3	4	5	6	12	24	∝
1	164.4	199.5	215.7	224.6	230.2	234.0	234.9	249.0	254.3
2	18.5	19.2	19.2	19.3	19.3	19.3	19.4	19.5	19.5
3	10.1	9.6	9.3	9.1	9.0	8.9	8.7	8.6	8.5
4	7.7	6.9	6.6	6.4	6.3	6.2	5.9	5.8	5.6
5	6.6	5.8	5.4	5.2	5.1	5.0	4.7	4.5	4.4
6	6.0	5.1	4.8	4.5	4.4	4.3	4.0	3.8	3.7
7	5.6	4.7	4.4	4.1	4.0	3.9	3.6	3.4	3.2
8	5.3	4.5	4.1	3.8	3.7	3.6	3.3	3.1	2.9
9	5.1	4.3	3.9	3.6	3.5	3.4	3.1	2.9	2.7
10	5.0	4.1	3.7	3.5	3.3	3.2	2.9	2.7	2.5
11	4.8	4.0	3.6	3.4	3.2	3.1	2.8	2.6	2.4
12	4.8	3.9	3.5	3.3	3.1	3.0	2.7	2.5	2.3
13	4.7	3.8	3.4	3.2	3.0	2.9	2.6	2.4	2.2
14	4.6	3.7	3.3	3.1	3.0	2.9	2.5	2.3	2.1
15	4.5	3.7	3.3	3.1	2.9	2.8	2.5	2.3	2.1
16	4.5	3.6	3.2	3.0	2.9	2.7	2.4	2.2	2.0
17	4.5	3.6	3.2	3.0	2.8	2.7	2.4	2.2	2.0
18	4.4	3.6	3.2	2.9	2.8	2.7	2.3	2.1	1.9
19	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.9
20	4.4	3.5	3.1	2.9	2.7	2.6	2.3	2.1	1.8
22	4.3	3.4	3.1	2.8	2.7	2.6	2.2	2.0	1.8
24	4.3	3.4	3.0	2.8	2.6	2.5	2.2	2.0	1.7
26	4.2	3.4	3.0	2.7	2.6	2.5	2.2	2.0	1.7
28	4.2	3.3	3.0	2.7	2.6	2.4	2.1	1.9	1.7
30	4.2	3.3	2.9	2.7	2.5	2.4	2.1	1.9	1.6
40	4.1	3.2	2.9	2.6	2.5	2.3	2.0	1.8	1.5
60	4.0	3.2	2.8	2.5	2.4	2.3	1.9	1.7	1.4
120	3.9	3.1	2.7	2.5	2.3	2.2	1.8	1.6	1.3
∝	3.8	3.0	2.6	2.4	2.2	2.1	1.8	1.5	1.0

III and IV show that values of F of 7.2 and 13.8 are required if the data are to be considered statistically significant at the 1 percent and 0.1 percent levels, respectively. Since the value of F in this problem is considerably smaller than even the smallest of these three values, it must be concluded that there is no statistically significant difference between the welding times on castings made with the dry sand or CO_2 sand as opposed to green sand. The foundryman would indeed be foolish to change his molding practice over to dry sand or CO_2 sand on the basis of these data.

One more example will be shown to further illustrate the use of the F test. In this example, the melting superintendent is investigating the service life of the silica brick used in his electric furnace roof. Over the past two years, he has been purchasing roofing brick from four different suppliers, Suppliers A, B, C and D. He has kept careful records of the number of heats per roof which were possible with each supplier's brick and feels that all the furnace roofs were subjected to the same melting conditions. His records show the number of heats per roof for the four suppliers to be:

	A	B	C	D
	175	193	172	179
	181	179	164	186
	169	194	167	175
	179	190	160	184
			177	
Totals	704	756	840	724
Average	176	189	168	181

The F test can be used to determine the significance of these data. The summary of calculations is as follows:

TABLE III—Table of Variance Ratio

1% Significance Level

Number of Degrees of Freedom in the Greater Variance Estimate (or Numerator Term)

Number of Degrees of Freedom in the Lesser Variance Estimate (or Denominator Term)	1	2	3	4	5	6	8	12	24	∞
1	4052	4999	5403	5625	5764	5859	5981	6106	6234	6366
2	98.5	99.0	99.2	99.3	99.3	99.4	99.3	99.4	99.5	99.5
3	34.1	30.8	29.5	28.7	28.2	27.9	27.5	27.1	26.6	26.1
4	21.2	18.0	16.7	16.0	15.5	15.2	14.8	14.4	13.9	13.5
5	16.3	13.3	12.1	11.4	11.0	10.7	10.3	9.9	9.5	9.0
6	13.7	10.9	9.8	9.2	8.8	8.5	8.1	7.7	7.3	6.9
7	12.3	9.6	8.5	7.9	7.5	7.2	6.8	6.5	6.1	5.7
8	11.3	8.7	7.6	7.0	6.6	6.4	6.0	5.7	5.3	4.9
9	10.6	8.0	7.0	6.4	6.1	5.8	5.5	5.1	4.7	4.3
10	10.0	7.6	6.6	6.0	5.6	5.4	5.1	4.7	4.3	3.9
11	9.7	7.2	6.2	5.7	5.3	5.1	4.7	4.4	4.0	3.6
12	9.3	6.9	6.0	5.4	5.1	4.8	4.5	4.2	3.8	3.4
13	9.1	6.7	5.7	5.2	4.9	4.6	4.3	4.0	3.6	3.2
14	8.9	6.5	5.6	5.0	4.7	4.5	4.1	3.8	3.4	3.0
15	8.7	6.4	5.4	4.9	4.6	4.3	4.0	3.7	3.3	2.9
16	8.5	6.2	5.3	4.8	4.4	4.2	3.9	3.6	3.2	2.8
17	8.4	6.1	5.2	4.7	4.3	4.1	3.8	3.5	3.1	2.7
18	8.3	6.0	5.1	4.6	4.3	4.0	3.7	3.4	3.0	2.6
19	8.2	5.9	5.0	4.5	4.2	3.9	3.6	3.3	2.9	2.5
20	8.1	5.9	4.9	4.4	4.1	3.9	3.6	3.2	2.9	2.4
22	7.9	5.7	4.8	4.3	4.0	3.8	3.5	3.1	2.8	2.3
24	7.8	5.6	4.7	4.2	3.9	3.7	3.3	3.0	2.7	2.2
26	7.7	5.5	4.6	4.1	3.8	3.6	3.3	3.0	2.6	2.1
28	7.6	5.5	4.6	4.1	3.8	3.5	3.2	2.9	2.5	2.1
30	7.6	5.4	4.5	4.0	3.7	3.5	3.2	2.8	2.5	2.0
40	7.3	5.2	4.3	3.8	3.5	3.3	3.0	2.7	2.3	1.8
60	7.1	5.0	4.1	3.7	3.3	3.1	2.8	2.5	2.1	1.6
120	6.9	4.8	4.0	3.5	3.2	3.0	2.7	2.3	2.0	1.4
∞	6.6	4.6	3.8	3.3	3.0	2.8	2.5	2.2	1.8	1.0

TABLE IV—Table of Variance Ratio

0.1% Significance Level

Number of Degrees of Freedom in the Greater Variance Estimate (or Numerator Term)

Number of Degrees of Freedom in the Lesser Variance Estimate (or Denominator Term)	1	2	3	4	5	6	8	12	24	∝
1	varies from 400,000 to 600,000									
2	998	999	999	999	999	999	999	999	999	999
3	167	148	141	137	135	133	131	128	126	123
4	74.1	61.3	56.2	53.4	51.7	50.5	49.0	47.4	45.8	44.1
5	47.0	36.6	33.2	31.1	29.8	28.8	27.6	26.4	25.1	23.8
6	35.5	27.0	23.7	21.9	20.8	20.0	19.0	18.0	16.9	15.8
7	29.2	21.7	18.8	17.2	16.2	15.5	14.6	13.7	12.7	11.7
8	25.4	18.5	15.8	14.4	13.5	12.9	12.0	11.2	10.3	9.3
9	22.9	16.4	13.9	12.6	11.7	11.1	10.4	9.6	8.7	7.8
10	21.0	14.9	12.6	11.3	10.5	9.9	9.2	8.5	7.6	6.8
11	19.7	13.8	11.6	10.4	9.6	9.1	8.3	7.6	6.9	6.0
12	18.6	13.0	10.8	9.6	8.9	8.4	7.7	7.0	6.3	5.4
13	17.8	12.3	10.2	9.1	8.4	7.9	7.2	6.5	5.8	5.0
14	17.1	11.8	9.7	8.6	7.9	7.4	6.8	6.1	5.4	4.6
15	16.6	11.3	9.3	8.3	7.6	7.1	6.5	5.8	5.1	4.3
16	16.1	11.0	9.0	7.9	7.3	6.8	6.2	5.6	4.9	4.1
17	15.7	10.7	8.7	7.7	7.0	6.6	6.0	5.3	4.6	3.9
18	15.4	10.4	8.5	7.5	6.8	6.4	5.8	5.1	4.5	3.7
19	15.1	10.2	8.3	7.3	6.6	6.2	5.6	5.0	4.3	3.5
20	14.8	10.0	8.1	7.1	6.5	6.0	5.4	4.8	4.2	3.4
22	14.4	9.6	7.8	6.8	6.2	5.8	5.2	4.6	3.9	3.2
24	14.0	9.3	7.6	6.6	6.0	5.6	5.0	4.4	3.7	3.0
26	13.7	9.1	7.4	6.4	5.8	5.4	4.8	4.2	3.6	2.8
28	13.5	8.9	7.2	6.3	5.7	5.2	4.7	4.1	3.5	2.7
30	13.3	8.8	7.1	6.1	5.5	5.1	4.6	4.0	3.4	2.6
40	12.6	8.2	6.6	5.7	5.1	4.7	4.2	3.6	3.0	2.2
60	12.0	7.8	6.2	5.3	4.8	4.4	3.9	3.3	2.7	1.9
120	11.4	7.3	5.8	5.0	4.4	4.0	3.5	3.0	2.4	1.6
∝	10.8	6.9	5.4	4.6	4.1	3.7	3.3	2.7	2.1	1.0

Supplier A	x_1	x_1^2	Supplier B	x_2	x_2^2
175	15	225	193	33	1089
181	21	441	179	19	361
169	9	81	194	34	1156
179	19	361	190	30	900
704	64 = Σx_1	1108 = Σx_1^2	756	116 = Σx_2	3506 = Σx_2^2

Supplier C	x_3	x_3^2	Supplier D	x_4	x_4^2
172	12	144	179	19	361
164	4	16	186	26	676
167	7	49	175	15	225
160	0	0	184	24	576
177	17	289	724	84 = Σx_4	1838 = Σx_4^2
840	40 = Σx_3	498 = Σx_3^2			

Preliminary Calculations -

$$\Sigma x = \Sigma x_1 + \Sigma x_2 + \Sigma x_3 + \Sigma x_4$$
$$= 64 + 116 + 40 + 84$$
$$\Sigma x = 304$$
$$\Sigma x^2 = \Sigma x_1^2 + \Sigma x_2^2 + \Sigma x_3^2 + \Sigma x_4^2$$
$$= 1108 + 3506 + 498 + 1838$$
$$\Sigma x^2 = 6950$$
$$N = N_1 + N_2 + N_3 + N_4 = 4 + 4 + 5 + 4 = 17$$

Correction Factor =

$$CF = \frac{(\Sigma x)^2}{N} = \frac{(304)^2}{17} = 5436$$

Total Sum of Squares =

$$\Sigma x^2 - CF = 6950 - 5436 = 1514$$

There are 17 items and therefore 16 d.f.

Between Sample Sum of Squares =

$$\frac{(\Sigma x_1)^2}{N_1}+\frac{(\Sigma x_2)^2}{N_2}+\frac{(\Sigma x_3)^2}{N_3}+\frac{(\Sigma x_4)^2}{N_4}-CF=$$

$$\frac{(64)^2}{4}+\frac{(116)^2}{4}+\frac{(40)^2}{5}+\frac{(84)^2}{4}-5436=$$

$$1024+3364+320+1764-5436=1036$$

There are 4 samples and therefore 3 d.f.

Within Sample Sum of Squares =

Total Sum of Squares minus Between Sample Sum of Squares = 1514 − 1036 = 478.

There are 16 minus 3, or 13 d.f.

Variance Between Samples =

$$\frac{1036}{3}=345.3 \qquad (3 \text{ d.f.})$$

Variance Within Samples =

$$\frac{478}{13}=36.8 \qquad (13 \text{ d.f.})$$

$$F=\frac{\text{Greater Variance Estimate}}{\text{Lesser Variance Estimate}}$$

$$=\frac{345.3}{36.8}$$

$$F=9.38\frac{(3)}{(13)}$$

Reference to Tables of Variance Ratio shows that the data are statistically significant at the 1 percent level.

The reader will note that a refinement has been introduced in order to simplify the calculations. The arbitrary quantity 160 has been subtracted from every term of the original data. Thus, Supplier A's data, for example, are listed under the column x_1 as 15, 21, 9 and 19 instead of 175, 181, 169 and 179. This has the effect of simplifying the calculations, but will not affect the final value of F. This can save considerable time, especially if a calculating machine is not available. All other calculations in this example are done exactly in the same manner as described in the previous example.

In this example the value of F is found to be 9.38, with 3 degrees of freedom in the greater variance estimate and 13 degrees of freedom in the lesser variance estimate. Tables II, III and IV show that a minimum value of F of 3.4, 5.7 and 10.2 is required for significance at the 5 percent, 1 percent and 0.1 percent levels, respectively. Therefore, these data are significant at the 1 percent level. On the basis of these data, the melting supervisor can conclude that there is a significant difference in the quality of the bricks which are being supplied.

The reader might find it interesting to compare any two of the suppliers by use of the t test. A comparison of Supplier A and Supplier B would show a significant difference to exist; a comparison of Supplier B and Supplier C would also show a significant difference to exist. However, a comparison of Supplier B and Supplier D would not show a significant difference to exist. This means that additional data would be required before it could be concluded that Supplier B's bricks were better than Supplier D's bricks.

EXPERIMENTAL DESIGN AND ANALYSIS OF VARIANCE

Frequently the foundry experimenter will find it difficult, if not impractical, to keep all variables constant except the one which he is investigating. For example, take the case illustrated in the previous section where the foundryman was interested in learning whether the use of dry sand or CO_2 sand molds would decrease the amount of welding time necessary on castings made in green sand molds. In order to keep as many variables as possible constant, the experimenter probably would have had the same welder weld all the castings. It is very likely, however, that in actual production, more than one welder is assigned to the job of welding this particular type of casting. Is it necessary then for this foundryman to repeat the same experiment with each of the various welders who work on this type of casting? The answer is no. This experiment can easily be designed so that both the effect of different molding sands and the effect of different welders can be investigated at the same time with a minimum number of test castings.

This technique can best be illustrated by working an example similar to the one shown previously. The foundryman will again be trying to determine whether dried sand molds or CO_2 sand molds can be used to reduce the amount of welding time required on a particular casting ordinarily made in green sand. Instead of using one welder to weld all the castings, two welders, Welder A and Welder B, will be employed; each welder will weld half of the total number of castings made. It should be pointed out that this is an entirely different casting than the one used in the previous example, therefore the results need not necessarily be the same.

The experimenter decides to make a total of 18 castings, 6 in green sand, 6 in dry sand, and 6 in CO_2 sand. The two welders will each weld 9 castings. The results of the experiment, with welding time in minutes, are as follows:

		Molding Medium			Welder Totals
		Green Sand	Dry Sand	CO_2 Sand	
Welder	A	12	9	11	101
		16	8	9	
		15	9	12	
	B	14	11	9	97
		12	7	11	
		15	10	8	
Sand Totals		84	54	60	

The statistical test known as the *Analysis of Variance* will now be used to determine if a significant difference between molding mediums and between welders exists. The calculations involved in the Analysis of Variance are very similar to those used in the F test described previously. The use of the Analysis of Variance to determine the significance of these data can best be illustrated by showing all calculations and then discussing each step:

Preliminary Calculations =

Σx = Grand Total

$\Sigma x = 12+16+15+\ldots+11+8=198$

Σx^2 = Sum of Squares

$\Sigma x^2 = (12)^2+(16)^2+(15)^2+\ldots+(11)^2+(8)^2=2298$

N = Number of Items

$N=18$

Correction Factor =

$$CF=\frac{(\Sigma x)^2}{N}=\frac{(198)^2}{18}=2178$$

Between Molding Sand Sum of Squares =

$$\frac{(84)^2}{6}+\frac{(54)^2}{6}+\frac{(60)^2}{6}-CF=$$

$1176+486+600-2178=84$

Between 3 molding sands there are 2 degrees of freedom.

Between Welder Sum of Squares =

$$\frac{(101)^2}{9}+\frac{(97)^2}{9}-CF=$$

$1133.4+1045.4-2178=0.8$

Between 2 welders there is 1 degree of freedom.

Total Sum of Squares $=\Sigma x^2-CF=$

$2298-2178=120$

Between 18 items there are 17 degrees of freedom.

TABLE OF ANALYSIS OF VARIANCE

Source	Sum of Squares	d.f.	Variance Estimate
Molding Sands	84	2	$\frac{84}{2}=42$
Welders	0.8	1	$\frac{0.8}{1}=0.8$
Residual	35.2	14	$\frac{35.2}{14}=2.5$
Total	120	17	

$$F_{sand}=\frac{\text{Variance Between Sands}}{\text{Residual Variance}}=\frac{42}{2.5}\quad\frac{(2)}{(14)}$$

$$F_{sand}=16.8\,\frac{(2)}{(14)}$$

Reference to Tables of Variance Ratio shows the difference between molding sands to be statistically significant at the 0.1 percent level.

$$F_{welder}=\frac{\text{Variance Between Welders}}{\text{Residual Variance}}=\frac{0.8}{2.5}\quad\frac{(1)}{(14)}$$

$$F_{welder}=0.32\,\frac{(1)}{(14)}$$

Reference to Tables of Variance Ratio shows that the difference between welders is not statistically significant.

The *Preliminary Calculations* show the calculation of the terms Σx, Σx^2 and N. The term Σx is the sum of all 18 entries in the table. The term Σx^2 is the sum of the squares of each item. N is the total number of specimens made in the experiment. The *Correction Factor* is determined just as before. It will enter into all further sums of squares which are directly computed.

In order to get the *Between Molding Sand Sum of Squares,* we find the sum of the square of each molding sand total divided by the number of items making up that total, and finally subtract the Correction Factor. The number of degrees of freedom is one less than the number of different molding mediums, and is therefore 2.

The *Between Welder Sum of Squares* is found in the same manner. We find the sum of the square of each welder total divided by the number of items making up that total, and then subtract the Correction Factor. The number of degrees of freedom is one less than the number of welders, and is therefore 1.

The *Total Sum of Squares* is the sum of the squares of all the items minus the Correction Factor. The number of degrees of freedom is one less than the number of items, and is therefore 17.

The results will now be collected together in the *Table of Analysis of Variance.* The reader will notice that in addition to the components of variation which have been calculated, the table also contains an extra entry under the title, "Residual." Out of a Total Sum of Squares equal to 120, the molding sands and welder sources only accounted for $84 + 0.8 = 84.8$. A sum of squares of magnitude $120-84.8=35.2$ were still unaccounted. This sum of squares, which is a measure of the variation not explained by molding medium and welder effects, is entered as "Residual." Its degrees of freedom $(17-2-1=14)$ are the degrees of freedom not accounted for by molding medium and welder effects. This Residual can be considered an ignorance or error factor which will enter into the calculation of the variance ratio, F.

Values of F can now be calculated to determine whether the difference between the three molding sands and the difference between the two welders is statistically significant. The variance ratio, F, for determining if a statistically significant difference exists between molding sands, is denoted by F_{sand}. This value of F is seen to be the ratio of the Variance Between Sands to the Residual Variance. The value of F_{sand} is seen to be 16.8 with 2 degrees of freedom in the numerator and 14 degrees of freedom in the denominator. Referring to Tables II, III and IV, it is seen that values of F of at least 3.7, 6.5 and 11.8 are required for significance at the 5 percent, 1 percent, and 0.1 percent levels, respectively. The value of F_{sand} of 16.8 is therefore statistically significant at the 0.1 percent level. This is a highly significant indication that the use of both dry sand molds and CO_2 sand molds were effective in reducing the amount of welding time required on this particular casting.

The variance ratio, F, for determining if a statistically significant difference exists between the two welders is denoted by F_{welder}. This value of F is the ratio of the Variance Between Welders to the Residual Variance. The value of F_{welder} is seen to be 0.32 with 1 degree of freedom in the numerator and 14 degrees of freedom in the denominator. Referring to Tables II, III and IV, it is seen that values of F of at least 4.6, 8.9 and 17.1 are required for significance at the 5, 1 and 0.1 percent levels, respectively. Therefore, the value of F_{welder} of 0.32 is not statistically significant. This indicates that there is no real difference in the performances of Welders A and B in welding this particular casting.

A mention of *interactions* should be made at this point, just for the record. An interaction would be a possible combination of the molding sand and welder effects. For example, the Analysis of Variance could be used to test whether one welder could weld the dry sand castings better than the other welder. From a practical foundryman's standpoint, any consideration of an interaction such as this would be foolish. In a more complex experiment of a different nature, interactions might be very important and can be determined with the use of the Analysis of Variance. In the foundry, interactions can often be very important.

In any foundry experiment of this nature there is always the chance that some outside factor may bias the experiment. If the experiment just illustrated had been carried out in a laboratory or a pilot foundry rather than in the middle of a production shop, outside factors possibly could be eliminated. Conduction of experiments without curtailing operations in the foundry will, in many cases, introduce variables into the experiment such as variable pouring temperature, variable mold hardness, operator fatigue, etc. In order to minimize the chance of the experiment being biased by one of these outside factors, an excellent technique is to randomize the order of the trials. For example, in the preceding illustration, this might have been done by making a dry sand casting first and having it welded by Welder B, then making a green sand casting and having it welded by Welder A, etc. This, of course, can be done in a much more sophisticated manner, as will be illustrated in the next example.

In this example, an experiment very similar to the one just shown (i.e., a 3 x 2 type of design) will be illustrated. In addition to showing the calculations, all the details of randomizing the trials will also be demonstrated.

In this experiment suppose that the sand technician is interested in learning which of three different sand mixtures is superior in resistance to scabbing and erosion defects on castings. Since all of the castings in his foundry are made in either green sand or skin dried molds, it would be desirable to try the different sand mixes with both green sand and skin dried molds. A casting which is very prone to scabbing and erosion (such as the Steel Founders' Society's scab test block casting) would be chosen as a test casting. Test castings will be made using each of the three sand mixtures, some in green sand molds and some in skin dried molds, and then will be evaluated by visual examination for scab and erosion defects. The castings will be evaluated according to the following rating scale:

0 — Excellent
1 — Slight defects
2 — Poor
3 — Very bad

After evaluation, the data will be analyzed using the Analysis of Variance in exactly the same manner as in the previous example.

It is again decided to make 18 test castings, 6 each of sand mixes A, B and C. Half of the 18 castings will be made in green sand molds and half in skin dried molds. This will yield 3 castings of each of the possible combinations. The technique of randomizing the order of making and pouring the molds will now be illustrated. The first two columns in the worksheet shown in Table V show how all possible combinations of sand mixtures and type of mold may be easily set up. The reader will note that there are three trials of each combination present. All that remains is to assign random numbers so that the experimenter may decide the order in which each mold will be made and subsequently poured. This is done as shown in the third column of Table V. The order of random numbers from 1 to 18 which are shown have been taken from published tables of random numbers. If no tables are available, however, drawing numbers out of a hat would be just as effective.

Rearranging this initial worksheet, the experimenter now will have the final worksheet as shown in Table VI. This is a more convenient worksheet

TABLE V—Arrangement Worksheet for Experimental Design

Sand Mix	Mold	Random Number
A	Green	3
A	Green	16
A	Green	12
A	Skin Dry	7
A	Skin Dry	10
A	Skin Dry	6
B	Green	8
B	Green	1
B	Green	5
B	Skin Dry	11
B	Skin Dry	14
B	Skin Dry	4
C	Green	13
C	Green	2
C	Green	17
C	Skin Dry	18
C	Skin Dry	9
C	Skin Dry	15

TABLE VI—Final Worksheet Showing Order of Molding and Pouring Molds

Casting Number	Sand Mix	Mold
1	B	Green
2	C	Green
3	A	Green
4	B	Skin Dry
5	B	Green
6	A	Skin Dry
7	A	Skin Dry
8	B	Green
9	C	Skin Dry
10	A	Skin Dry
11	B	Skin Dry
12	A	Green
13	C	Green
14	B	Skin Dry
15	C	Skin Dry
16	A	Green
17	C	Green
18	C	Skin Dry

for the experimenter to use in directing the molder and pouring crew as he supervises the experiment. After all of the molds are made in the order shown in Table VI, they should then be skin dried (where necessary), closed, and poured in the same order as they were molded. This will tend to eliminate systematic bias from such factors as molder fatigue and pouring temperature, thereby making the results of the experiment more meaningful.

After shot blasting, the castings are evaluated by the experimenter. Let us assume that the ratings for the 18 castings were as follows:

1 - 0	10 - Lost
2 - 2	11 - 1
3 - 2	12 - 1
4 - 2	13 - 3
5 - 1	14 - 0
6 - 2	15 - 1
7 - 2	16 - 3
8 - 1	17 - 2
9 - 1	18 - 2

The reader will note that in this hypothetical example one of the test castings, Number 10, was lost due to the mold breaking out during pouring. This might easily occur in actual practice, and is shown so that the reader may see that it will not ruin the experiment.

The experimenter can then draw a chart and substitute the above data as follows:

		Sand Mixture			Mold Totals
		Mix A	Mix B	Mix C	
Mold	Green	3 - 2 12 - 1 16 - 3	1 - 0 5 - 1 8 - 1	2 - 2 13 - 3 17 - 2	15
	Skin Dry	6 - 2 7 - 2 10 - Lost	4 - 2 11 - 1 14 - 0	9 - 1 15 - 1 18 - 2	11
Sand Mixture Totals		10	5	11	

The reader might find it interesting to refer back to Tables V and VI to assure himself that the data and casting numbers have been placed in the correct positions in the above chart. The Analysis of Variance can then be performed to test the significance of the data. The calculations are made in exactly the same manner as in the previous example:

Preliminary Calculations -

Σx = Grand Total

$\Sigma x = 2+1+3 \ldots +1+2=26$

Σx^2 = Sum of Squares

$\Sigma x^2 = (2)^2+(1)^2+(3)^2+ \ldots + (1)^2+(2)^2=52$

N = Number of Items = 17

Correction Factor =

$$CF=\frac{(\Sigma x)^2}{N}=\frac{(26)^2}{17}=39.8$$

Between Sand Mixture Sum of Squares =

$$\frac{(10)^2}{5}+\frac{(5)^2}{6}+\frac{(11)^2}{6}-CF=$$

$20.0+4.2+20.2-39.8=4.6$

Between 3 sand mixtures there are 2 degrees of freedom.

Between Mold Sum of Squares =

$$\frac{(15)^2}{9}+\frac{(11)^2}{9}-CF=$$

$$25.0+15.1-39.8=0.3$$

Between 2 types of molds there is 1 degree of freedom.

Total Sum of Squares $=\Sigma x^2-CF=$

$52-39.8=12.2$

Between 17 items there are 16 degrees of freedom.

TABLE OF ANALYSIS OF VARIANCE

Source	Sum of Squares	d.f.	Variance Estimate
Sand Mixture	4.6	2	$\frac{4.6}{2}=2.3$
Mold	0.3	1	$\frac{0.3}{1}=0.3$
Residual	7.3	13	$\frac{7.3}{13}=0.56$
Total	12.2	16	

$$F_{sand}=\frac{\text{Variance Between Sand Mixtures}}{\text{Residual Variance}}$$

$$=\frac{2.3}{0.56}\qquad\frac{(2)}{(13)}$$

$$F_{sand}=4.11\frac{(2)}{(13)}$$

Reference to Tables of Variance Ratio shows the difference between sand mixtures to be statistically significant at the 5 percent level.

$$F_{mold}=\frac{\text{Variance Between Molds}}{\text{Residual Variance}}$$

$$=\frac{0.3}{0.56}\qquad\frac{(1)}{(13)}$$

$$F_{mold}=0.54\frac{(1)}{(13)}$$

Reference to Tables of Variance Ratio shows that the difference between green sand and skin dried molds is not statistically significant.

The value of F_{sand} is seen to be equal to 4.11 with 2 degrees of freedom in the numerator and 13 degrees of freedom in the denominator. Reference to the Tables of Variance Ratio shows that this value is statistically significant at the 5 percent level. Hence, the experimenter can be reasonably certain that sand mix B is more resistant to scabbing and erosion than are sand mixes A and C. The value of F_{mold} is seen to be not statistically significant, indicating that the green sand mold and the skin dried molds are essentially the same in their resistance to scabbing and erosion.

The above illustrations of the use of the Analysis of Variance are only a scratch on the surface of what can be done with this powerful experimental tool. Larger and more complex experimental designs can be incorporated to statistically examine variable after variable in the foundry practice and determine the resultant effect on casting quality and cost. Unfortunately, an introductory paper such as this can do no more than introduce the reader to some of the techniques that can be used to make sound technical and operational decisions in the foundry. However, the interested reader could easily become very proficient through a study of the reference books listed below.

SUMMARY

An introduction to the use of recognized statistical techniques as a guide to making sound decisions in the foundry has been given. All that is necessary for the understanding of these techniques is a knowledge of simple arithmetic. The "t" test, the "F" test and the Analysis of Variance have been illustrated along with sample problems presented in such a way as to simulate actual foundry experiences. It should be pointed out that statistical techniques such as those illustrated have been used for many years in some related industries. Although these techniques are relatively new to the foundry industry, they are nevertheless being used daily with great success.

ACKNOWLEDGMENT

The author wishes to thank Mr. J. Ramsey Speer, Jr., of Texas Foundries, Inc., for all the time he has devoted to discussing statistical techniques with the author and for his review of the final draft of this manuscript.

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(Continued on Page 18)

DEVELOPMENT OF "AS-CAST" GRAIN REFINER FOR CAST STEEL

by

G. K. Turnbull*, G. W. Form and J. F. Wallace*****

The following is a summary of a technical report prepared by the Department of Metallurgical Engineering of Case Institute of Technology in cooperation with Watertown Arsenal's Rodman Laboratory.

ABSTRACT

Various substances were added to molten low carbon steel in an attempt to develop methods by which the as-cast structure of steel could be grain-refined. The selection of the additions was based either on their capability to provide finely distributed centers for heterogeneous nucleation or on their potency of producing appreciable constitutional supercooling to interrupt continuous growth of the first formed crystallites. Considerable effort was directed toward developing suitable means of delineating the as-cast grain size from various structural features which persisted through the allotropic transformation when cooling to room temperature. As inoculants, titanium carbide and vanadium boron were found particularly effective, while columbium and titanium proved to be suitable solute additions to interrupt grain growth. Mechanical properties were determined for those castings in which appreciable grain refinement of the as-cast structure was obtained. Generally, the results showed an improvement in strength which, however, was accompanied by a loss in ductility and notch toughness.

MATERIALS AND PROCEDURE

The principal objective of this study was the development of commercially feasible methods to grain refine steel by means of suitable additions. To accomplish this aim, the investigation was divided into three parts: first, a general evaluation of the problem of grain refining steel was made; second, small scale tests to achieve refinement were performed; and third, promising grain refining procedures were applied to commercial practice. The initial portion of the investigation encompassed a theoretical evaluation of possible grain refining additions, based on crystallographic, density, and stability considerations. Five potential inoculants were then selected on the basis of this theoretical analysis, and a group of large steel castings was poured, each casting (except the standard) being inoculated with one of these additions. The first group of experiments was unsuccessful in producing grain refinement but brought out many important aspects, in particular the necessity for close control of the governing parameters. Based on these results, an extended series of closely controlled tests with twenty-pound castings was initiated. The purpose of these experiments was to evaluate additional substances which appeared favorable. The most promising of these additions was then introduced into a fifteen-hundred pound heat of low-alloy steel.

Potentially suitable inoculants were originally chosen on the basis of good lattice registry with the base metal. The solidification of low carbon steel involves the selection of grain refiners with close crystallographic matching with either austenite or delta iron. Since the delta phase constitutes the primary crystallites, however, the attention was focused on the nucleation of this structure. It was assumed that the development of many fine delta particles in the liquid was desirable in itself and would result in a finer austenitic grain size during the subsequent peritectic reaction. Among the crystallographically favorable substances, only those which were sufficiently stable in the parent liquid were feasible. This excluded additions which melt at a temperature substantially lower than steel or which dissolve easily in molten steel.

Although most inoculants are soluble to some extent in liquid steel, the time dependency of dissolution will permit an interval for effective inoculation. This requires, of course, a close control over the time elapsing between the introduction of the addition and actual solidification. While the dissolution aspects limit the effectiveness of an addition when large castings or high pouring temperatures are involved, it has the advantage that it provides for a clean surface which otherwise cannot readily be attained. The chemical reaction of a given inoculant with steel could be assessed to some extent from known phase relationships and known thermodynamic data. It was not possible, however, from the limited information available, to determine the reaction of such a particle with other solutes present in the melt. Some restriction on the selection of suitable inoculants was also imposed by density considerations. A large difference in density between addition and steel may lead to marked segregation by gravity, particularly when the particle size is coarse.

First Group of Experiments: Large Castings

Various inoculants listed in Table I were added to a series of six 1800-pound melts that were subsequently poured into cylindrical green sand molds. The metal for these castings was melted as one large

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TABLE I—Inoculants Added to Large Castings of AISI 1030 Steel

Inoculant Added (Wt. %)	Crystal Structure	Density (gm/cm^3)	Melting Point (°F)
0.5 TiC	NaCl	4.25	5880
0.5 K_2TiF_6	(See data for Ti and TiC)*		
0.5 Zr	BCC	6.50	3380
0.5 Ti	BCC	4.54	3128
0.5 Ca	BCC	1.55	1486

* It was expected that K_2TiF_6 would dissociate at the high temperatures to form Ti or TiC which would act as inoculants.

heat in a commercial five-ton direct acid electric arc furnace. As each ladle, containing about 1800 pounds of molten steel, was tapped from the arc furnace, deoxidation was accomplished with a two pound per ton addition of aluminum. Then, each ladle of molten steel was treated with a selected inoculant. A large steel plunger that was held below the surface until the addition had completely reacted was employed for adding these inoculants. Additions of pig iron, ferro-manganese and ferro-silicon were made to the furnace during the course of the heat in an attempt to compensate for oxidation losses. In spite of the fact that all castings were poured from a single heat, substantial variations in chemistry occurred because of the oxidation losses in the furnace and compensating addition to the furnace. The most critical of these variations was a range of carbon content from 0.225 to 0.393 percent. This latter variation produced considerable influence on the mechanical properties. A typical time interval from the beginning of inoculation to the completion of pouring was five minutes, including a pouring time of forty-five seconds.

Extensive metallographic examination was conducted on a transverse slice of each casting cut 13 inches from the bottom. Macro and microscopic studies were made both on the as-cast structure and after a heat treatment designed to delineate the segregates more clearly. The mechanical properties taken on these castings included Brinell hardness readings, tensile testing and impact transition curves. The bars were heat treated by either normalizing from 1650 degrees F or by water quenching from 1625 degrees F and tempering at 430 degrees F.

Second Group of Experiments: Small Castings

The investigation was continued with twenty-pound ingots poured under closely controlled conditions. The base metal for this portion of the experiment was AISI 1018 steel. The additions made to the individual castings were AlCo, TiC, ZrC, W, AlNi, V, Cb, Ti, Zr and B. These materials were added as either inoculants or grain growth inhibitors.

Each melt was prepared individually by melting twenty pounds of steel in a high frequency induction furnace. A charge consisting of 1018 bar stock was melted down before making any alloying or inoculating additions. Deoxidation was accomplished in the furnace with a 0.25 percent addition of aluminum. More aluminum than usually employed in commercial practice was utilized to minimize oxidation of the inoculants. Additions were introduced by plunging the inoculant attached to a graphite or steel plunger below the surface of the melt and stirring. The slag was then removed from the melt and the casting poured. The pouring temperature was maintained at 2975 degrees F $\pm$25 degrees F. After treatment the molten steel was poured into a cast iron chill mold with an inside diameter of 5 inches and a wall thickness of 5/16 inch seated on a 1½ inch thick steel chill block. This arrangement permitted rapid directional solidification from the base and sides.

Metallographic examinations were conducted on longitudinal cross sections of each casting. Sulfur prints of this section gave an indication of the degree of segregation encountered. Each ingot was subsequently reground and macroetched with either cupric ammonium chloride (Humfrey's Reagent) or a 50 percent aqueous solution of nitric acid. Specimens were cut from selected castings for microscopic examination. Tensile tests were conducted on a series of castings containing additions which proved to be effective grain refiners. Individually cast bars 2 inches in diameter and 5 inches long were poured in sand molds after treatment with additions of titanium and titanium carbide. Tensile bars were machined 0.020 inch oversize from each casting, austenitized at 1650 degrees F, water quenched, drawn at 350 degrees F for one hour, finish machined and tested.

Third Experiment: Large Low-Alloy Castings

The results of the small, closely controlled castings permitted the selection of a most promising inoculant on which to conduct further tests. Two 1500-pound cylindrical castings of the type made in the first group of experiments were poured from a single heat of 0.20 carbon Cr-Ni-Mo alloy steel. One casting served as a control without addition and the other determined the effectiveness of TiC as an inoculant.

These two castings were analyzed by testing procedures similar to those used for the first group of six large castings. The tests included macro and micro-examination, tensile properties and Charpy impact tests.

RESULTS AND DISCUSSION

First Group of Experiments: Large Castings

This group of castings was treated with additions intended to act as inoculants. A comparison of each casting with the control shows that a slight reduction in the as-cast grain size was achieved through the addition of these various inoculants.

Etched samples were studied at high magnification to determine the amount and distribution of the inoculating particles in the melt. The control and the calcium-inoculated castings contained only spherical, Type I sulfides. The similarity in type, amount and distribution of segregates in these two castings can be taken as evidence of the poor recovery of calcium because of its low boiling temperature.

Examination of the castings containing additions of titanium in various forms revealed TiC/TiN mixtures. These compounds were present in every casting to which titanium was added, and their extent provided at least a qualitative measure for the amount of titanium retained in the steel. These were located in the ferritic portion of the microstructure without exception, and their shape was either square or triangular with the boundary sharply outlined. The zirconium-inoculated steel contained elongated ZrC/ZrN particles. Although these particles were predominantly located within the ferrite, it was not uncommon for these to occur in pearlite.

The recovery of inoculants varied considerably: the titanium in the K_2TiF_6 salt was mostly retained in the melt; the TiC and calcium additions were not well retained. The low recovery of the TiC must be primarily attributed to a malfunctioning of the plunger which caused the major portion of the inoculant to remain on the surface of the melt in the ladle where it was subsequently entrapped by the slag. The low recovery of calcium (about 6 percent) was associated with its low boiling point as a result of which the calcium escaped as a gas or was oxidized during the violent reaction. The effect of the five inoculants on the mechanical properties was assessed by tensile tests, conducted either in the quenched and tempered or the normalized condition. The results assembled in Table II indicate an improved yield and tensile strength in all treated castings compared to the control. This improvement in strength was accompanied by a marked reduction in ductility. Since the refinement of the as-cast structure was only slight and the ductility decreased, the increased strength level must be attributed primarily to an alloying effect. The exact reason for the loss in ductility could not be determined, but it is believed that a brittle grain boundary precipitate may be responsible for it. Whether this embrittlement can be alleviated through appropriate heat treatments or not remains to be ascertained.

TABLE II—Mechanical Properties of Large Steel Castings

Inoculant Added (Wt. %)	Tensile Strength (KSI)	Yield Strength (KSI)	Elongation (%)
Normalized			
Control	86.2	57.5	23.8
0.5% TiC	86.8	62.5	20.9
0.5% K_2TiF_6	88.0	63.2	14.2
0.5% Zr	88.0	—	16.4
0.5% Ti	86.4	68.7	8.8
0.5% Ca	94.5	68.2	16.0
Quenched and Tempered at 430°F			
Control	199.0		
0.5% TiC	202.9		
0.5% K_2TiF_6	214.9		
0.5% Zr	216.5		
0.5% Ti	177.9		
0.5% Ca	188.3		

The results obtained in V-notch Charpy impact testing showed that generally, inoculation shifted the ductile-brittle transition energy to lower temperatures, but reduced the supertransition level. The titanium-inoculated exhibited a decreased toughness at all temperatures.

Second Group of Experiments: Small Castings

Various quantities of up to one percent of a variety of substances were added to twenty-pound ingots of 1018 steel. Titanium carbide and vanadium boron were found to be particularly effective in reducing the columnar length, while tungsten, AlCo and AlNi had no perceptible effect on the columnar structure. A grain growth inhibiting effect was achieved with small solute additions of columbium and titanium. Although solute additions of boron, zirconium and vanadium exerted a very pronounced effect on the resulting macrostructural appearance, a positive identification of the as-cast grain size by microscopic examination was not possible in these castings.

Since simultaneous additions of titanium and titanium carbide produced the most consistent grain refinement, a series of cylindrical bars were cast to determine the effect of these additions on mechanical properties. The results listed in Table III show that both yield and tensile strength increased with the amount of titanium and titanium carbide, while the ductility suffered an appreciable loss. As discussed previously for the large size castings, the overall effect of the above additions was not believed to be due to variations in grain size alone but also to an alloying effect. Moreover the presence of precipitates, such as TiC along the grain boundaries may well contribute to the embrittlement tendency.

TABLE III—Mechanical Properties of Titanium and Titanium Carbide Inoculated Small Castings

Additions %Ti	Additions %TiC	Tensile Strength (KSI)	Elongation %	Reduction In Area %
0	0	69.0	24.5	58.6
.1	.1	79.6	3.0	6.6
.1	.5	95.3	3.0	3.7
.3	.1	85.2	3.0	4.9
.3	.5	86.7	2.0	1.2

Third Experiment: Large Low-Alloy Castings

In view of the successful grain refinement achieved with TiC in small heats, it was decided to inoculate a large heat of a 0.20 percent carbon low alloy steel with this carbide. A control and a TiC-treated casting were poured at Watertown Arsenal from a single heat of chromium-nickel-molybdenum steel. The chemical analyses showed that the basic composition of the two castings was quite similar. The fact, however, that the titanium content differs only very slightly between the control and the treated casting (.006 percent versus .010 percent) points to a very low titanium retention in the inoculated casting. This factor, unfortunately, limited the differences in structure and properties in the two castings. In spite of the very low titanium retention, as suggested by the chemical analysis, the inoculated casting showed a significant reduction in the length of the columnar zone. On the other hand, inoculation did not appear to have a visible effect on the size of the equiaxed center grains. An attempt to determine by sulfur printing whether the large columnar grains in the control casting represented the as-cast structure or whether these grains were the result of grain growth occurring during the slow cooling was inconclusive, presumably because of insufficient sulfur in the steel. Microstructural analysis revealed the presence of TiC/TiN particles in the treated but not in the control casting. The appearance and location of these particles was the same as discussed for the corresponding AISI 1030 casting.

The results obtained in mechanical testing after heat treatment to a high strength level showed, in general, that inoculation with TiC had no discernible effect on strength, but reduced both ductility and toughness as previously observed.

General Discussion

This investigation indicates some of the major difficulties encountered when grain refining the as-cast structure of steel. The identification of the grain size prevalent at the end of freezing requires a detailed and thorough analysis of all those facets which are inherited from the as-cast grain boundary or dendritic structure, and which persist during the allotropic transformation occurring on cooling to ambient temperature. The relatively high melting point of steel restricts the number of potentially suitable inoculants because of the stability requirement imposed on such substances. In addition, some of the very promising additions which could act as potent grain growth inhibitors oxidize readily at the high temperatures involved and are either rejected into the slag or remain as oxides in the melt. In either case, the potential of these additions to produce appreciable constitutional supercooling is markedly reduced. This problem, as well as the gradual dissolution of insufficiently stable inoculants introduces a time factor into the problem of grain refinement particularly in large, slowly solidifying castings.

The method selected for introducing the addition to the molten steel should provide a fine uniform distribution, and avoid too much reactivity of the grain refining substance with the prevailing atmosphere and the constituents in the steel. Additions that appear promising on the basis of theoretical considerations will only produce successful refinement of the as-cast structure if properly added and alloyed to remain in the melt in an active state. None of the castings that were grain refined in this present study produced an improvement in ductility. In fact, the ductility was generally reduced by these additions. This loss in ductility is attributed to constituents within the grain boundaries. Additional work is required to establish whether this ductility can be restored by various heat treatments or different grain refining materials.

CONCLUSIONS

1) Inoculation of five 1800-pound castings of a low carbon, low alloy steel heat by small amounts of Ti, TiC, K_2TiF_6, or Ca resulted in only minor variations in as-cast grain size or interdendritic spacing.

2) The mechanical properties of these inoculated large castings displayed improvements in strength, when compared with the untreated casting, and generally a lowering of the ductile-to-brittle transition temperature. All inoculated castings, however, suffered an appreciable loss in room temperature tensile ductility. In view of the relatively small effect of any of the above inoculants on the as-cast grain size, the variations in mechanical properties must, at least partially, be attributed to an alloying effect.

3) Of the inoculants added to a variety of 20-pound castings of AISI 1018 steel, titanium carbide and vanadium boron proved to be most effective in producing a fine equiaxed center zone of appreciable length. A considerable grain growth inhibiting effect was achieved with small amounts of columbium titanium.

4) Simultaneous additions of titanium and titanium carbide resulted in the most consistent grain refinement of these small castings. A series of castings inoculated with various amounts of these two additions was therefore subjected to room temperature

tensile tests. The results showed an improvement in strength and a loss in ductility when compared with the standard casting. The embrittlement was tentatively attributed to grain boundary precipitation.

5) A 1500-pound casting of chromium-nickel-molybdenum steel inoculated with 0.5 percent TiC showed some reduction in the length of the columnar zone. The very low titanium retention in the melt, however, limited the expected difference in structure and properties as compared to the untreated casting. Inoculation of this casting had no discernible influence on strength, but affected both ductility and notch impact toughness adversely.

SFSA RESEARCH REPORT No. 46

ELEMENTS OF DESIGN FOR PREVENTION OF HOT TEARING IN STEEL CASTINGS

PART III—JOINING OF STRESS ACTIVE SECTIONS

The studies were carried on in the Foundry Division of Massachusetts Institute of Technology under the direction of Professor H. F. Taylor for the purpose of investigating the variation in the design of sections and its effect on hot tears in steel castings.

The research studies covered the investigation of the effect of section design and the effect of the direction of stress action on various casting members with the idea of finding possible means of formulating design rules for the prevention of hot tears at joining members. A number of design rules for the prevention of hot tears were formulated in SFSA Research Report No. 38. The studies presented in this report were concerned with a continuation and extension of the elements of design with box sections and flanged fittings as examples of joining sections with built-in active stresses similar to those found in the production of commercial steel castings.

Castings of a box design and flanged fittings were studied as stress active systems because both the mold and section design can result in hindered contraction and the formation of stress which produces hot tears in steel castings.

The box section castings were varied as to corner design, section tapering and wall thickness in order to produce different conditions of stress application, stress concentration and hot spots. The outside ⅛ inch radius of the box section was held constant and the inside radius was varied from ⅛ inch to 1½ inches. Various tapers from 0.035 inch/inch were used. The wall sections investigated were ¾ inch and ⅜ inch. The test castings were pressure blasted and examined: (1) visually, (2) by X-ray inspection of thin sections, and (3) visually after a deep acid etch.

Hot tear experiments were performed on two sizes of castings of 3¼ and 6-inch bore diameters to investigate the elimination of bore cracks. One end of the casting was maintained as a control with constant gating and risering while various experimental changes were made at the test end.

The findings of the investigations permit the following conclusions:

1. Tapering is an extremely effective way of reducing hot tearing in stress active joining sections, such as box section castings. Tapering is far more effective than radiusing the corners, even though radiusing does reduce hot tearing.
2. Corner designs with a radiused internal corner and a sharp external corner (accentuated corner hot spot) tear under stress conditions when shrinkage exists in the corner near the inside fillet.
3. Hot tearing can be prevented if design and foundry procedures are such as to promote adequate feeding.
4. Effective techniques are illustrated for minimizing and eliminating bore cracks in flanged fittings. These techniques depend on obtaining adequate feeding by improved gating, risering, chilling and padding methods.

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SFSA RESEARCH REPORT No. 47

THE DEVELOPMENT OF EFFECTIVE BENTONITE CLAY BONDS FOR STEEL FOUNDRY SANDS

There existed a need for a systematic study on the effect of bentonite as a bonding clay in molding sands for steel foundry use. The Technical Research Committee of Steel Founders' Society recognized the need for such basic research, although it realized the results may not be readily applied in a practical way to the commercial production of steel castings. Experimental studies were conducted at the Foundry Division of Massachusetts Institute of Technology under the direction of Professor H. F. Taylor. The report containing these studies was reviewed by the Technical Research Committee and submitted to Dr. W. G. Lawrence of Alfred University to review, revise, and edit as a research report for the member companies.

The investigations in this report were limited to a study of the constitution and properties of bentonite so that steel foundrymen may better understand the characteristics of bentonite and its ability to bond silica sand. The investigation included: (1) a study of the variables influencing the behavior of bentonite and sand-bentonite-water mixtures; (2) a study of the molding abilities and molded properties of sand with different types of bentonite; (3) a study of the bonding forces between bentonite and silica sand.

The salient features of the research on bentonite as a bonding agent of steel foundry molding sands are as follows:

1. The liquid limit and swelling volume of bentonites are related to the type of ion associated with the mineral.
2. The dry strength of bentonite is directly related to the swelling volume and to particle size of the bentonite which, in turn, results in a more continuous and uniform coating of the sand grains.
3. Those bentonites which have high swelling volume require more water to reach maximum strength, and they also have higher dry strengths.
4. Various relationships were developed between the properties of the unconsolidated sand-bentonite-water (liquid limit, percent water), the energy applied to the system (degree of ramming), and the resulting properties of the compacted mass (workability, hardness).
5. The shear strength for any mixture of bentonite-water is independent of its thickness except at layer thicknesses below 0.015 cm which variation is the result of foreign material in the bentonite.
6. Shear strength of bentonite-water mixture is independent of the type of shearing surface.
7. Separation in a bentonite-silica system occurs in the clay-clay interface, not the clay-silica grain interface.
8. Improvement of bonding characteristics must be achieved by denser packing of the aggregates to obtain thinner bentonite layers around each grain or improvements in the bentonite-water system by chemical alteration.

ABSTRACTS OF FUNDAMENTAL PAPERS ON STEEL CASTING RESEARCH

Based on a review of the current literature on technical research subjects. (Copies of these articles available from original publishers only.)

Sand Research

Hofmann, F., "Specific-Surface and Grain-Structure of Foundry Sands," FOUNDRY TRADE JOURNAL, January 12, 1961. The author discusses the importance and the method of finding the specific-surface of foundry sands as well as the resulting method for the determination of the grain shape. A newly developed method is described which enables an experimental and quantitative determination of the inner grain structure to be found. This affects the consumption of core binders used with foundry sands.

Properties and Testing

Creech, M. D., "Quicker Diagrams Analyze Steel Fatigue," PRODUCT ENGINEERING, February 13, 1961. Constructing the true endurance diagram for a steel must be preceded by many hours of fatigue tests. Here the author introduces an approximate diagram suitable for most ductile steels. All that is needed are two properties of the steel: its ultimate strength and its yield strength. By applying the loading conditions to this approximate diagram, the allowable endurance limit can be quickly calculated.

Welding Research

Travis, R. E., Barry, J. M., Robinson, J. V., Moffatt, W. G., and Adams, C. M., Jr., "Fundamentals of Weld Behavior Under Hindered Contraction," WELDING RESEARCH SUPPLEMENT, February 1961. In hindered contraction of restrained test welds, the development of self-imposed loads has been found to depend systematically on the geometry and stiffness of restraint, the strength and hardenability of the filler and plate, and arc energy input. In the presence of a transverse bending moment, the factors which favor high restraint stresses also promote cracking, but without the bending moment, cracking will not occur.

Sand Bonding

Caine, J. B., King, E. H., and Schumacher, J. S., "Steel Foundry Sand Clay Bonding," MODERN CASTINGS, January 1961. The authors' findings show that the theories of uniform distribution of clay on sand grains and clay film thickness are possibly in error. Mulling over short intervals of time does not increase clay distribution as evaluated by this paper. The increase in green and dry strengths with increased mulling may not be due primarily to improved distribution of the bond. Techniques of specimen preparation for microscopic examination are given.

Sand Packing

Williams, D. C., "Granular Movement During Squeezing," MODERN CASTINGS, January 1961. Density of the sand adjacent to a squeeze board is greater than that found at the parting line of a flask. The author attempts to explain this using material from the discipline of soil mechanics. Granular movement during squeeze molding operations is divided between a movement toward a horizontal direction and a movement toward a vertical direction. The author suggests that better squeeze compaction would be accomplished if squeeze boards were decreased in size to take advantage of greater sand movement.

Solidification

Berry, J. T., and Watmough, T., "Factors Affecting Soundness in Alloys with Long and Short Freezing Range," MODERN CASTINGS, January 1961. After a brief discussion of major mold material and casting alloy variables upon the production of sound castings, specific study is made of two areas of topical interest:

1) The extent of the influence of mold material upon the feeding requirements of three short freezing range alloys.
2) The effect of applied pressure to the feeder head of castings made in various long freezing range alloys.

The particular alloys concerned were aluminum alloys No. 43, 220 and 355.

Properties and Testing

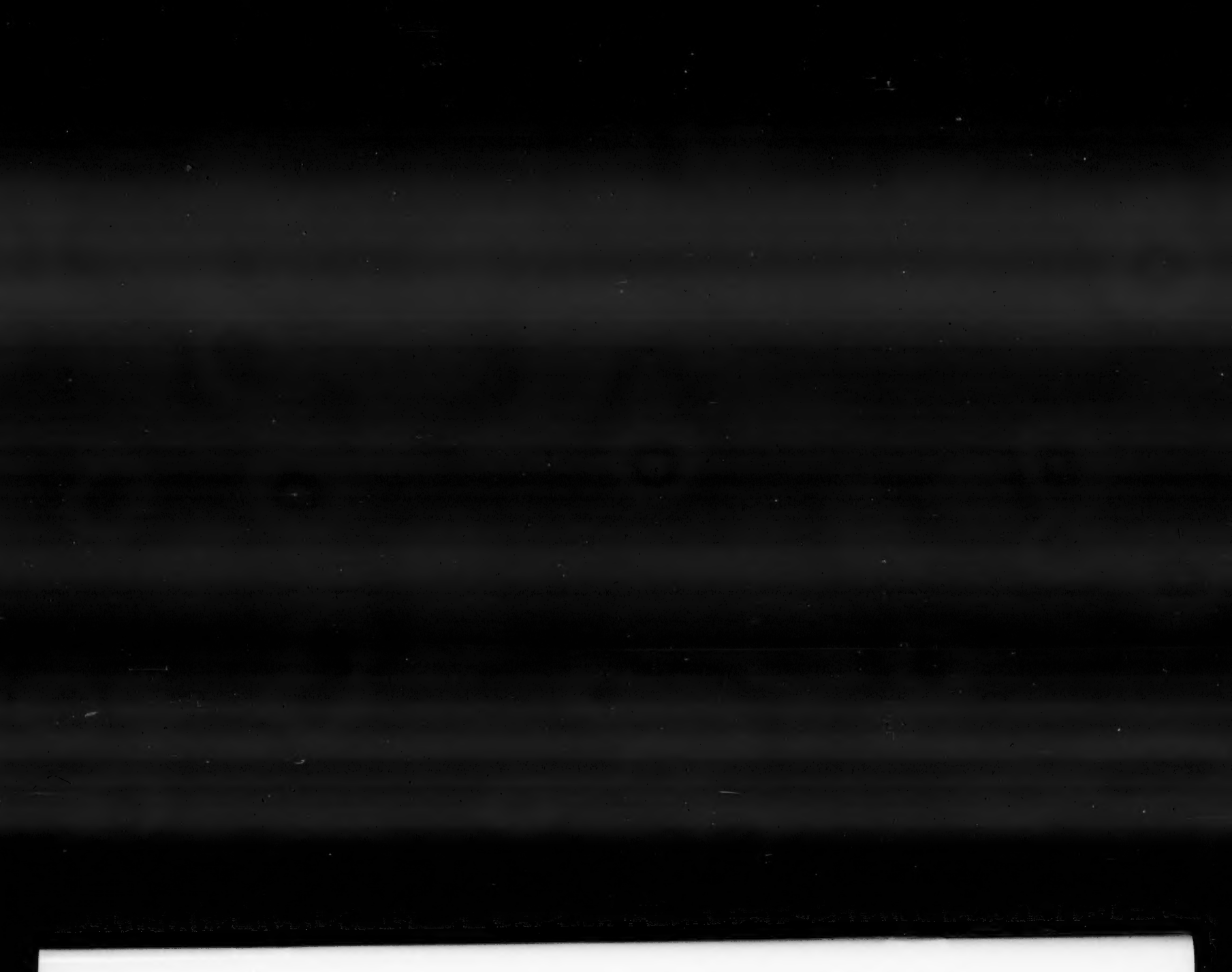
Curll, C. H., "Subsize Charpy Correlation with Standard Charpy," MATERIALS RESEARCH & STANDARDS, February 1961. To provide a means of impact acceptance testing of specimens that must be obtained from thin or small-diameter sections, a study was made using various specimen sizes, of the Charpy V-notch impact properties of alloy steels over a range of temperatures encompassing their transitions from ductile to brittle behavior. The test data tend to indicate a linear correlation between the energy required to fracture standard-size and subsize Charpy V-notch specimens at the normal acceptance-test temperature of −40 degrees F.

Risering

"An Evaluation of Feeding Heads and Feeding Aids for Castings," THE BRITISH FOUNDRYMAN, February 1961. A thorough evaluation of the methods of increasing feeding efficiency of steel, gray iron, nodular iron, malleable iron, copper-base, and aluminum-base castings is made. The influence of such feeding aids as insulating materials, carbonaceous riser covers, exothermic riser compounds, riser sleeves were investigated. General conclusions with regard to nature of the alloy, casting temperature, casting shape, influence of feeding aids, and economic aspects are made.

Melting

Hinnebusch, R. A., and McKinnon, J. A., "A Practical Method for Statistical Evaluation of Open Hearth Problems," Open Hearth Proceedings, Volume 43, 1960. The authors illustrate a practical method by which the interrelation of many variables inherent in many open hearth metallurgical problems can be evaluated. This method can be used whenever the problem involves correlation of two or more variables and, consequently, can be a useful tool in quality control programs. The method is simple and requires no specially trained technicians or costly equipment.

Vacuum Treatment

Harders, F., Knuppel, H., and Brotzmann, K., "Vacuum Treatment of Molten Steel," Open Hearth Proceedings, Volume 43, 1960. This paper is a review of operating experience with the Dortmund-Horder Huttenunion vacuum treatment process. In addition, new data on the properties of vacuum treated steel are presented, i.e., distribution of oxygen contents in the ingot section, number of stringer type oxides present, distribution of aluminum contents in the ingot, results of impact testing, etc. Work is also being done on desulfurization during treatment and on the removal of oxygen and/or carbon from high alloy grades which are inherently killed before treatment.